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E-4 Test Facility Design Status

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ABSTRACT

Combined-cycle propulsion technology is a strong candidate for meeting NASA space transportation goals. Extensive ground testing of integrated air-breathing/rocket systems (e.g., components, subsystems and engine systems) across all propulsion operational modes (e.g., ramjet, scramjet) will be needed to demonstrate this propulsion technology. Ground testing will occur at various test centers based on each center's expertise. Testing at the NASA John C. Stennis Space Center (SSC) will be primarily concentrated on combined-cycle power pack and engine systems at sea level static conditions at a dedicated test facility, E-4. This paper highlights the status of the SSC E-4 Test Facility design.

INTRODUCTION

NASA's **I**ntegrated **S**pace **T**ransportation **P**lan (ISTP) puts forward a strategy for safer, more reliable and less costly access to space (cf. Ref. 1). A component of the ISTP is the development of 3rd Generation **R**eusable **L**aunch **V**ehicle (RLV) Technologies such as combined-cycle propulsion systems. The development of 3rd Generation RLV Technologies falls under the purview of NASA's **A**dvanced **S**pace **T**ransportation **P**rogram (ASTP) with the associated goal of developing space transportation systems that are 100 times cheaper and 10,000 times safer than present launch vehicles.

One propulsion technology that is a strong candidate for meeting ASTP goals is the **R**ocket **B**ased **C**ombined **C**ycle (RBCC) propulsion system. Succinctly, an RBCC propulsion system uses atmospheric air as an oxidant during a portion of the vehicle's trajectory, thereby reducing the amount of oxidant that needs to be carried onboard the vehicle, which ultimately translates into greater vehicle payload capacity. The RBCC propulsion system has several operational modes including air-augmented rocket (AAR), ramjet, scramjet and rocket-only modes as the vehicle travels to orbit.

Recently, various testing and design studies associated with RBCC propulsion system technologies have successfully been completed, with the results warranting continued engine development. As the RBCC propulsion system continues to evolve under government and industry leadership, it is anticipated that extensive ground testing of RBCC components, subsystems and engine systems across all propulsion operational modes (e.g., ramjet, scramjet) will be required to further RBCC development. Ground testing will occur at a variety of test centers based on each center's expertise. The NASA John C. Stennis Space Center (SSC) has a long and distinguished history of testing mid- to large-scale cryogenic rocket systems [2-4]. Consequently, RBCC testing at SSC will be primarily concentrated on power pack and engine systems testing at sea level static conditions at a dedicated test facility, E-4. The E-4 Test

Facility at SSC is being specifically designed to accommodate the unique air-breathing and rocket-powered facets of the RBCC engine.

E-4 TEST FACILITY DESIGN

The planning of the E-4 Test Facility began in March 1999 when Sverdrup Technology, Inc. was tasked by NASA SSC to develop preliminary engineering requirements, facility options and cost estimates for a facility that would enable testing of RBCC propulsion systems. The Preliminary Engineering Report (PER) that was subsequently delivered to NASA SSC in August 1999 established thorough guidelines and costs for a Tripulse Propulsion Test Facility that would allow for static sea level, altitude and subsonic free jet testing of RBCC propulsion systems [5, 6].

With the continued success of sub-scale RBCC propulsion development testing, a decision was made to specifically design and construct the E-4 Test Facility at SSC which would incorporate some of the aspects of the Tripulse Propulsion Test Facility design detailed in the PER. Testing at SSC would primarily be concentrated on RBCC power pack and engine systems at sea level static conditions. Altitude simulation and ram air capability are catalogued as potential future developments of E-4. Hence, Sverdrup Technology, Inc. was commissioned by NASA SSC in October 2000 to design the majority of the E-4 Test Facility. Mississippi Space Services (MSS) was commissioned to design the Test Control Center (TCC) and the Prep Building associated with the E-4 Test Facility and it is expected that Lockheed Martin Stennis Operations (LMSO) at SSC will assist NASA SSC personnel to develop the E-4 Data Acquisition and Controls System (DACS). Completion of the E-4 Test Facility design is scheduled for October 2001 for all systems except the E-4 DACS, for which design begins in October 2001 and is expected to conclude one year later. Construction of the E-4 Test Facility is expected to be completed in 2004.

In broad terms, the E-4 Test Facility is capable of providing a low-pressure supply of propellants to RBCC test articles having a thrust up to 50,000 lbf. In addition, the facility design allows for the growth of test capabilities to meet future testing requirements of RBCC propulsion systems. These future capabilities include a 500,000 lbf thrust test capability and the placement of a ram air module ($M < 0.8$) for a 50,000 lbf-class test article. A solid model representation of the E-4 Test Facility, as currently designed, is shown in Fig. 1. The test article is situated in the test cell and fires in the horizontal direction with the plume directed towards the containment pond (i.e., in the northeast direction). An overview of the E-4 Test Facility capabilities, as currently designed, is presented next.

Site Location and Development

Several factors influenced the siting of the E-4 Test Facility. First and foremost, E-4 is located a safe distance from existing SSC facilities. The arrangement of the various facility structures is governed by the *NASA Safety Standard for Explosives, Propellants and Pyrotechnics* [7]. The NASA standard [7] is in place to ensure the safety of personnel and critical structures during an unlikely catastrophic propellant release or explosion at a **P**otential **E**xplosive **S**ite (PES). Examples of a PES include launch pads, static test stands and liquid propellant storage tanks. In general, the standard specifies the minimum distance, referred to as quantity-distance (Q-D),

needed between a PES and other facility structures. These Q-D distances are calculated based upon the amount of propellant and explosives at the PES.

Another E-4 location constraint is access. E-4 is sited such that personnel have access to E-4 at all times, even during testing at the A, B and other E-Complex Test Stands. In addition, E-4 is located near tie-in points to the site gas supplies (e.g., GN_2, GH_2), industrial water supply (or canal), the site electrical system and site roads.

Based on the aforementioned constraints, the E-4 Test Facility, once constructed, shall be located in the vicinity of the other E-Complex Test Stands (E1, E2 and E3) at SSC. An additional benefit of this location is that the role of E-4 and its expected capabilities are synergistic with the other E-Complex Test Stands [2]. The site in which the E-4 Test Facility will be constructed has recently been cleared of trees and other material, as shown in Figs. 2 and 3.

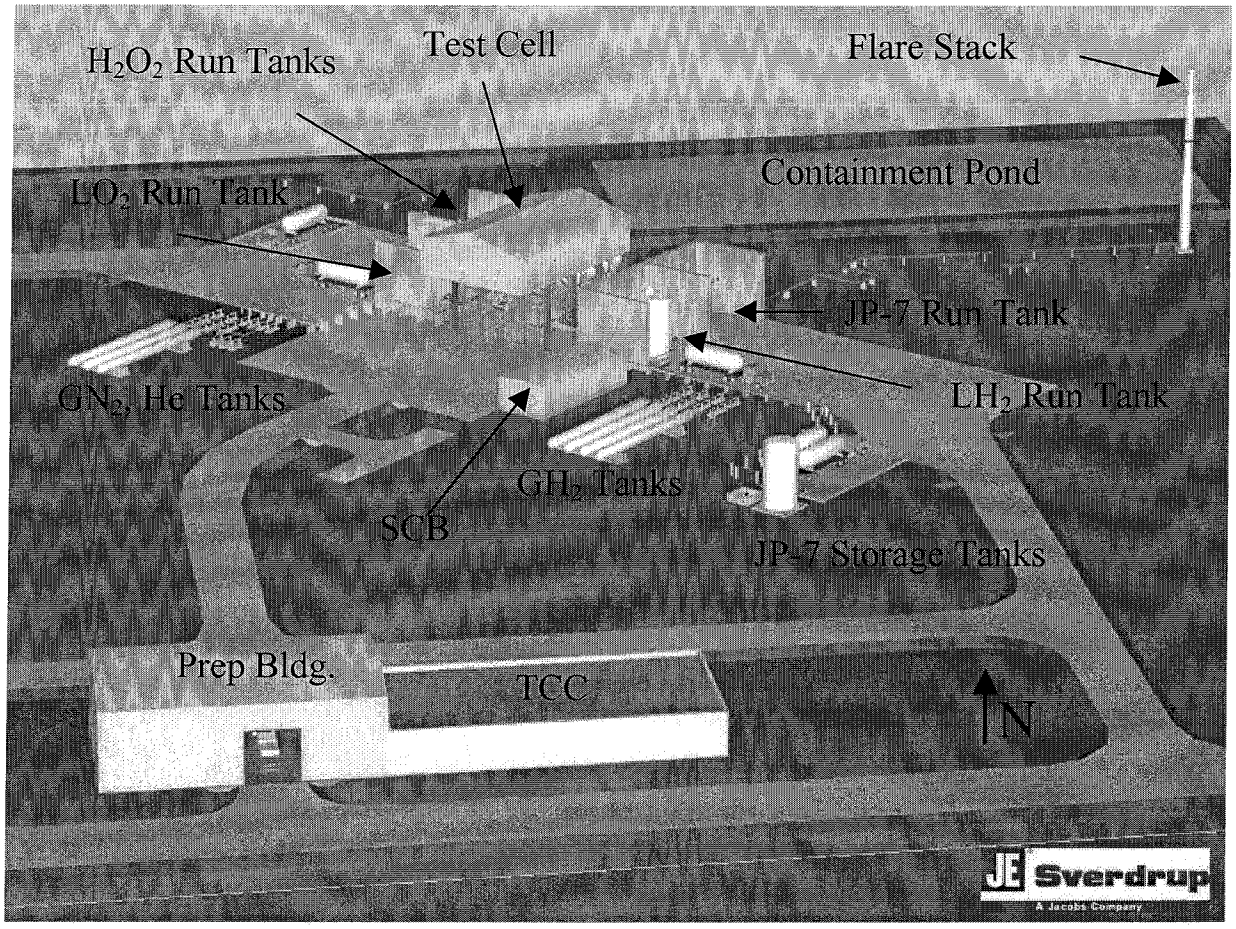

Fig. 1. The E-4 Test Facility.

Test Cell

The test cell, as shown in Fig. 4, was designed to accommodate both the near-term and long-term testing requirements of RBCC propulsion systems. With regards to thrust level, it is anticipated that RBCC propulsion systems will be tested up to 50,000 lbf in the near term. Assuming

successful testing at this size class of engine, it is expected that future testing requirements in terms of thrust could reach 500,000 lbf. Hence, the E-4 thrust stand foundation has been designed for a test article firing in the horizontal direction with a thrust level up to 500,000 lbf. The thrust stand structure itself and the thrust measurement system (TMS) are designed for a horizontal firing, 50,000 lbf thrust test article.

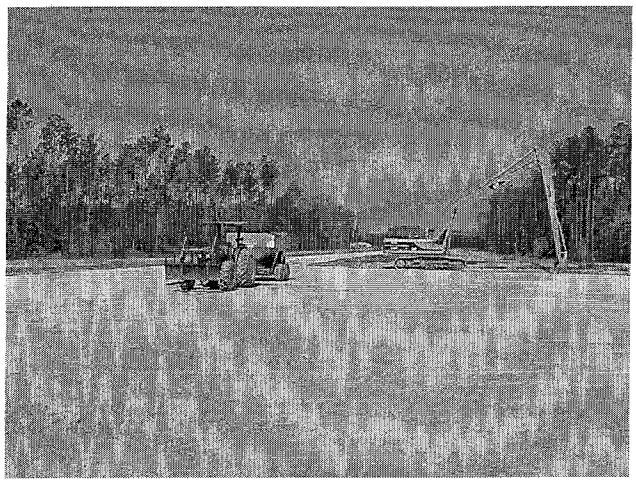

Fig. 2. View (looking west) of access road approaching the E-4 Test Facility.

Fig. 3. View (looking east from southwest corner of site) of the cleared area where the E-4 Test Facility will be constructed.

As surmised from Fig. 1, a concrete apron has been established in front of the test article inlet for several reasons. First, the concrete apron will reduce the likelihood of foreign debris being entrained into the test article. Second, the concrete apron can accommodate a flow conditioning and free-jet nozzle module that would be associated with a ram-air capability (Note: ram-air capability is a future development of the E-4 Test Facility).

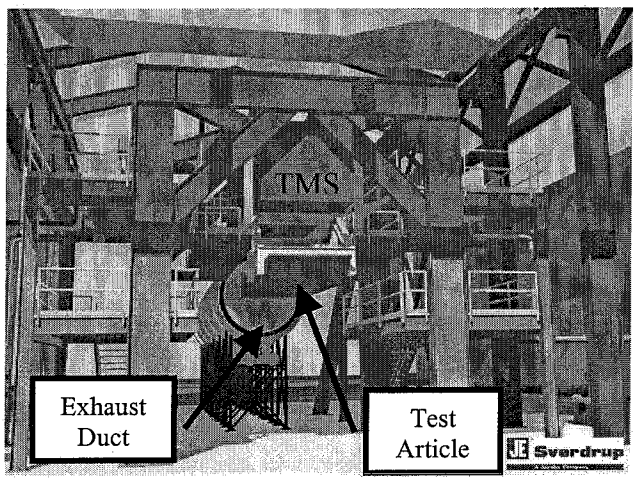

Fig. 4. The E-4 Test Cell area including the thrust measurement system (TMS), the test article and the exhaust duct.

The current E-4 test cell design also provides for overhead protection of the test cell and a 10-ton overhead crane that will allow for the handling and lifting of various facility and test article-related equipment in the test cell area.

Finally, a water-cooled exhaust duct (see Fig. 4) has been incorporated into the E-4 Test Cell design in order to protect the test facility from the heat associated with the test article plume. The exhaust duct will be necessary for extended test durations and if, potentially, a hydrocarbon fuel is employed during testing.

Propellant Systems

In order to obtain a greater degree of test capability flexibility, the E-4 Test Facility is designed to accommodate four (4) propellant systems: liquid hydrogen (LH_2), liquid oxygen (LO_2), hydrocarbon (HC) and hydrogen peroxide (H_2O_2), as shown in Fig. 1. In general, the propellant systems are designed to accommodate flow rates associated with a 50,000 lbf thrust test article for an extended run time.

The LH_2 system consists of a truck unloading station, a run tank, a flare stack and the associated piping. The LH_2 is pressurized using gaseous hydrogen (GH_2), and helium (He) is available for purging needs. The LH_2 run tank is a vacuum-jacketed vessel having a maximum allowable working pressure (MAWP) of 180 psig and is sized to accommodate chill down, ullage and reserve volumes. The LH_2 piping is vacuum-jacketed where necessary and has a MAWP of 600 psig. A flare stack is employed to safely consume unreacted hydrogen.

The LO_2 system consists of a truck unloading station, a run tank, a LO_2 dump pit and the associated piping. Gaseous nitrogen (GN_2) is used to pressurize and purge the LO_2 system. The LO_2 run tank is a vacuum-jacketed vessel having MAWP of 400 psig and is sized to accommodate chill down, ullage and reserve volumes. The LO_2 piping is insulated where necessary and has a MAWP of 600 psig. Unreacted oxygen is fed to the LO_2 dump pit.

The HC consists of a truck unloading station, a storage tank, a run tank, a dump tank and the associated piping. Gaseous nitrogen (GN_2) is used to pressurize and purge the HC system. The HC storage tank is a double-walled above ground vessel having a volume of five (5) times volume of the run tank volume and a MAWP of 15 psig. The HC run tank is a vessel having a MAWP of 400 psig and is sized to accommodate ullage and reserve volumes. The HC dump tank is a double-walled above ground vessel having a volume of two (2) times the volume of the run tank volume and a MAWP of 15 psig. Used HC propellant will be stored in the dump tank. The HC piping has a MAWP of 600 psig.

Hydrogen peroxide (H_2O_2) may be used as both a propellant (i.e., oxidant) and as a turbine drive fluid during RBCC testing. The H_2O_2 propellant system is referred to as the "bi-propellant" system, while the H_2O_2 turbine drive fluid system is referred to as the "monopropellant" system. The H_2O_2 system shall consist of a truck unloading station, a bi-propellant run tank, a monopropellant run tank, a catalyst bed, a containment pond and the associated piping. Gaseous nitrogen (GN_2) is used to pressurize the H_2O_2 system(s). Gaseous nitrogen (GN_2) and de-ionized (DI) water is used to purge and flush the H_2O_2 system(s). In general, the H_2O_2 system(s) are designed to accommodate up to 98% concentration H_2O_2. The bi-propellant H_2O_2 run tank is a vessel having a MAWP of 400 psig and is sized to accommodate ullage and reserve volumes. The monopropellant H_2O_2 run tank is a vessel having a MAWP of 1,400 psig, and once again, is sized to accommodate ullage and reserve volumes. The H_2O_2 piping has a MAWP of 600 psig. Unreacted H_2O_2 is directed to a catalyst bed prior to routing to a containment pond.

Electrical System Capabilities

The facility power system provides for 480/277 VAC three-phase, 208/120 VAC three/single phase and 240/120 VAC single-phase power.

A low-speed video system (60 frames/second) for facility and test article monitoring has been incorporated into the design. In addition, a high-speed video system (500 frames/second) has been designed for complete viewing of the test article.

Initiation of the E-4 Test Facility data acquisition and controls system (DACS) design is scheduled for October 2001. The DACS design typically encompasses a control system, a low- and a high-speed data acquisition system. Although synergism and consistency with other E-Complex DACS is preferable, the use of more capable and advanced systems is highly desirable and will be evaluated during the design.

Ancillary Facility Systems

A number of necessary ancillary systems are present at the E-4 Test Facility. A deluge water system, supplied by either a water tower or a pump system, provides fire protection to the test article area, propellant run and storage tanks and propellant unloading stations. A compressed air system and a hydraulic system are primarily used for valve actuation duties. A potable water system supplies the various safety showers, eye wash stations and fire hydrants placed throughout the E-4 Test Facility. In addition, building supply and fire sprinkler needs are satisfied by this system. Hazardous gas detectors, including O_2, H_2 and H_2O_2 detectors, are located throughout the facility. Finally, an intercom and public address system are incorporated into the E-4 Test Facility to allow for communication requirements.

Test Control Center (TCC) and Prep Building

As shown in Fig.1, the TCC and the Prep Building are located to the south of the test cell. The location of these buildings is based upon safety considerations (e.g., quantity distance arcs) and cable length requirements associated with the data acquisition and controls system (DACS). Tests are conducted from the TCC while all test article preparation work is performed in the Prep Building. The TCC is a hardened building capable of withstanding a 3.0-psi overpressure. During test article operation, personnel conducting the test are located in the control room inside the TCC. The TCC control room contains the facility and test article control system, the data acquisition system user interface and the test stand video monitoring system. Also housed within the TCC are several offices and a conference room to accommodate desktop work throughout testing.

The Prep Building consists of a high bay area, a work area and a tool storage area. The high bay area is large enough such that an 18-wheeler truck can drive into the high bay area, unload the test article using a 10-ton overhead crane and then drive out of the high bay area. It is envisioned that the test article will be transported from the high bay area into a conditioned work area for test preparation work using an engine handler. The conditioned work area (i.e., HVAC supplied) is equipped with a 1-ton overhead crane for lifting and handling of various components associated with the test article.

SUMMARY

As the RBCC propulsion system evolves from the current proof of concept phase into a flight demonstrator engine development program, the specific test needs for mid- to large-scale engines are becoming more apparent. To meet the need, the E-4 Test Facility is being designed with sufficient flexibility to accommodate both the near-term and long-term testing requirements for

RBCC powerpack and engine systems. In the current design, the E-4 Test Facility is capable of providing a low-pressure supply of propellants (e.g., potentially LH_2, LO_2, HC and H_2O_2) to RBCC test articles having a thrust up to 50,000 lbf. In addition, the E-4 design is such that future facility upgrades, such as a ram-air capability, can be implemented in a smooth manner. The E-4 design effort is scheduled to conclude in October 2001 and the initiation of the E-4 construction effort is to begin shortly thereafter. The aspects of the E-4 design that will get incorporated into the construction effort first will be those required to meet specific RBCC testing requirements. Construction of the E-4 Test Facility is expected to conclude in 2004.

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The authors would like to acknowledge the many NASA and contractor participants in the E-4 design activity. This includes personnel from several other NASA Centers (GRC, LaRC and MSFC), personnel from NASA SSC organizations (Propulsion Test Directorate, Center Operations and Support Directorate, and Safety and Mission Assurance) as well as personnel from SSC design support organizations (Mississippi Space Services, Lockheed Martin Stennis Operations). In addition, the authors recognize Sverdrup Technology, Inc. for their thorough E-4 Test Facility design effort.

REFERENCES

[1] NASA Marshall Space Flight Center web site content, http://std.msfc.nasa.gov.

[2] Stennis Space Center Test Facilities Capabilities Handbook, NP-2001-07-00011-SSC, Fourth Edition, September 2001.

[3] Rahman, S., Gilbrech, R., Lightfoot, R. and Dawson, M., "Overview of Rocket Propulsion Testing at NASA Stennis Space Center," 11th Annual Symposium on Propulsion, University Park, PA, November 18-19, 1999.

[4] Ryan, H.M., Rahman, S. and Gilbrech, R., "Current and Future Rocket Propulsion Testing at NASA Stennis Space Center," 12th Annual Symposium on Propulsion, Cleveland, OH, October 26-27, 2001.

[5] "Rocket Based Combined Cycle (RBCC) Engine Test Facility," Preliminary Engineering Report to NASA John C. Stennis Space Center, Volumes 1 and 2, August 1999.

[6] Smith, K. and Wagner, D., "Development of Static Sea Level Test Facilities for RBCC Engines," 36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, AIAA Paper 2000-3602, Huntsville, AL, July 17-19, 2000.

[7] Safety Standard for Explosives, Propellants and Pyrotechnics, NASA, NSS 1740.12, August 1993.

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